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ISOCS and SNAP™

Fundamentals of Nondestructive Assay for International Safeguards

Los Alamos National Laboratory

March 15-19, 2019

Steve Myers

LANL Retiree

LA-UR



SAFEGUARD NUCLEAR MATERIALS TO
PREVENT THEIR DIVERSION OR THEFT



CONTROL THE SPREAD OF WMD-RELATED
MATERIAL, EQUIPMENT AND TECHNOLOGY



NEGOTIATE, MONITOR AND **VERIFY**
COMPLIANCE WITH INTERNATIONAL
NONPROLIFERATION AND ARMS CONTROL
TREATIES AND AGREEMENTS



DEVELOP PROGRAMS AND STRATEGIES TO
ADDRESS EMERGING NONPROLIFERATION
AND ARMS CONTROL THREATS AND
CHALLENGES

ABSTRACT

- Students are taught the principles of ISOCS and SNAP™
- and their applications for measuring nuclear material
- Students will learn the applications for ISOCS and SNAP™
- Students will be able to describe the ISOCS analysis process
- Students will be able to describe the SNAP™ 4 step process
- Students will explain how ISOCS generates an efficiency curve
- Students will understand how to calculate a minimum detectable activity (MDA) in SNAP™ and ISOCS
- Students will know the corrections necessary to perform a simple assay estimate by hand calculation



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Terminal Learning Objective

Participants will understand the principles of ISOCS and SNAP™ and their applications for measuring nuclear material

Enabling Learning Objective

- Define ISOCS and SNAP™
- List applications for ISOCS and SNAP™
- Describe the ISOCS analysis process
- Describe the SNAP™ 4 step analysis process
- Explain how ISOCS generates an efficiency curve
- Understand how to calculate a minimum detectable activity (MDA) in SNAP™
- Know the corrections necessary to perform a simple assay estimate by hand calculation

What is ISOCS?

ISOCS = In-Situ Object Counting System

- Consists of software and characterized detectors from Canberra
- Determines absolute efficiency through mathematical modeling and knowledge of detector properties
- Used for quantification of nuclear and radiological material
 - Mass
 - Activity

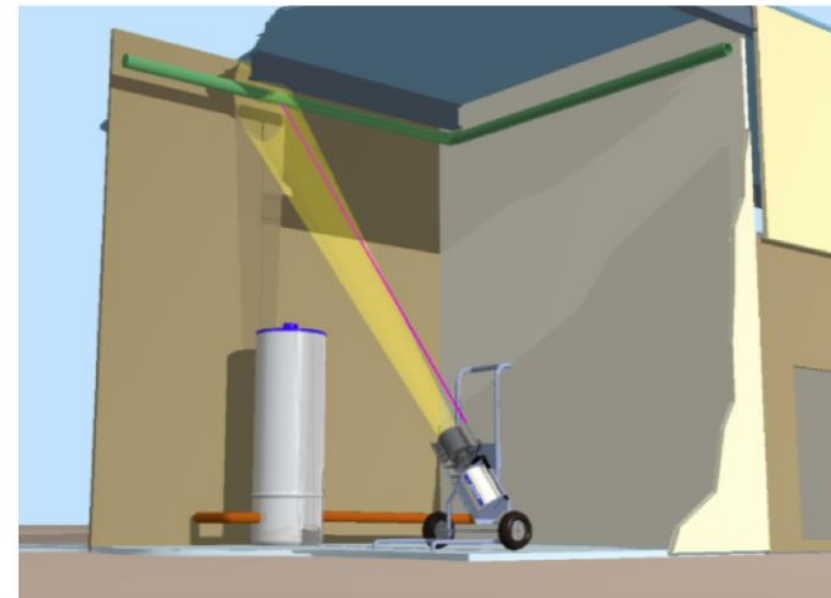




ISOCS Applications

Applications where no calibration standard is available or practical to use

- Holdup
- Waste characterization
- Environmental characterization of radioactive contamination
- Many others, ISOCS is a very flexible method





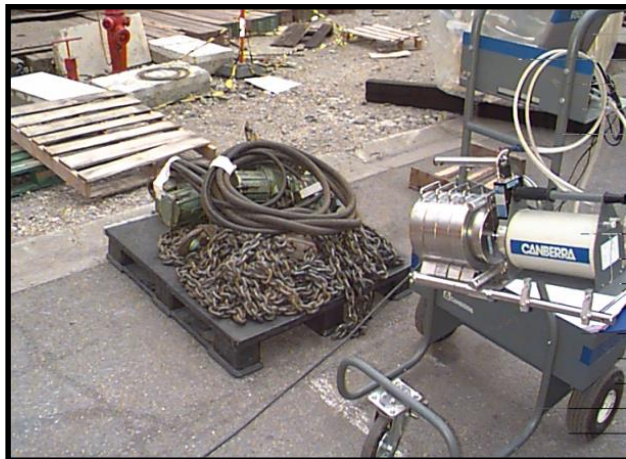
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ISOCS Applications





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ISOCS Measurement Process

- Characterizing detector at the factory
- Acquiring spectral data from the object
- Specifying the dimensions and physical composition of the measured object
- Generating an efficiency curve specific for the specified measurement configuration
- Using the efficiency curve to analyze the acquired spectra to calculate activity or mass



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Traditional Definition of Efficiency

Efficiency of a detection system: defined as the detector's observed (measured) peak area count rate divided by the expected gamma emission rate for that gamma energy

$$\text{Efficiency} = \frac{\text{number of photons registered by detector}}{\text{number of photons emitted by the source}}$$

Efficiency Components

- Efficiency is specific to each particular measurement configuration and is dependent on a variety of factors
- Factors contributing to the full (absolute) efficiency:
 - Geometry of nuclear material (distance, shape, etc.)
 - Attenuation (container walls, absorbers, etc.)
 - Object self-attenuation (attenuation in nuclear material)
 - Intrinsic efficiency (efficiency of the detector crystal)

$$\epsilon_{full} = \epsilon_{geom} \cdot \epsilon_{atten} \cdot \epsilon_{self} \cdot \epsilon_{int}$$

Classic Efficiency Calibration - Measured

- Well-characterized calibration source in fixed position from the detector
- Measure detector response to the known mass of material
- Calculate calibration coefficient

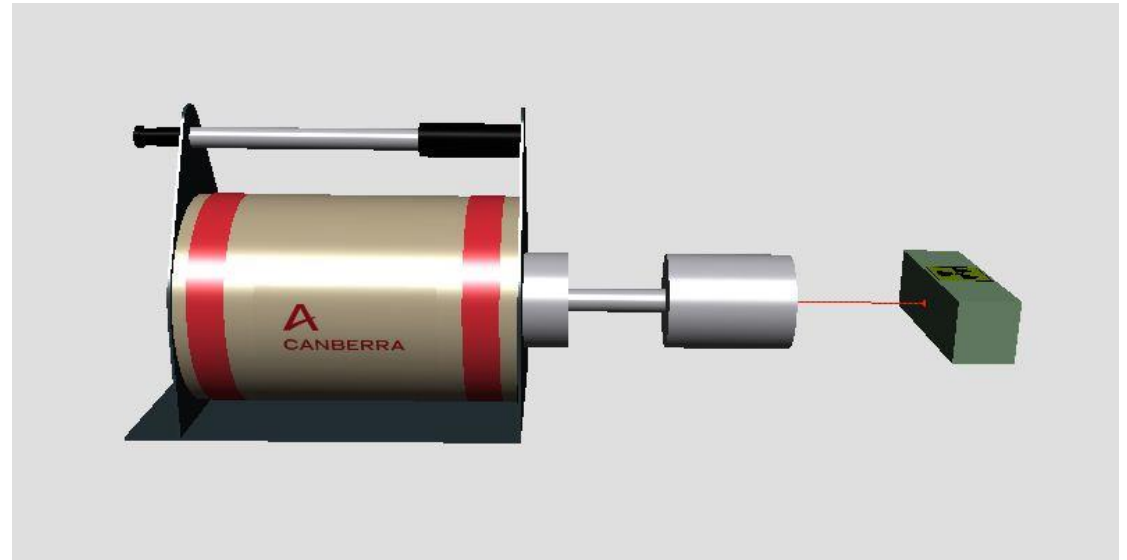
$$m = k \cdot CR$$

where

m – mass of the item

k – calibration coefficient

CR – count rate in the
detector



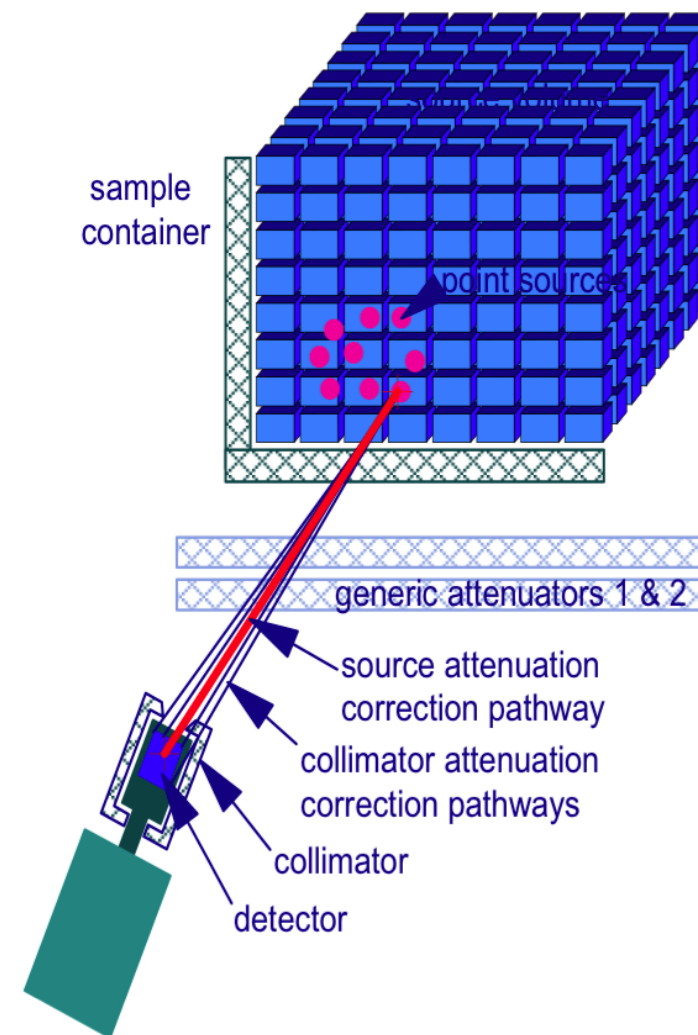
Note, this calibration is dependent on the source-to-detector distance and geometry of the nuclear material



ISOCS Efficiency Calibration - Calculated

ISOCS allows the determination of the absolute efficiency without using a calibration source

- Develop an MCNP model of the detector that reproduces a set of measurements collected at the factory
- Using this model and the MCNP code, generate a large lookup table that presents efficiency versus position versus energy for unattenuated point sources
 - This table is the “detector characterization” – it is customized for each detector



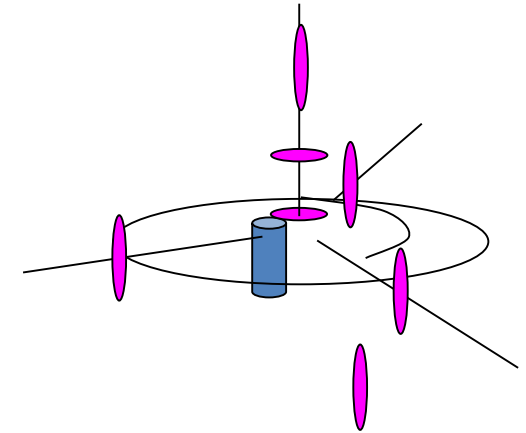
Detector Characterization

Performed at factory

- All HPGe detectors are unique
 - Detectors can be made with various diameter and height combinations
 - Variable dead-layer [front, sides, back]
- These parameters are not well known from the manufacturing process
- They cannot be determined by measuring a source
 - But we need to know them accurately
 - Use combination of manufacturing dimensions and multiple radiation measurements under carefully controlled conditions

Detector Characterization – NM Measurements

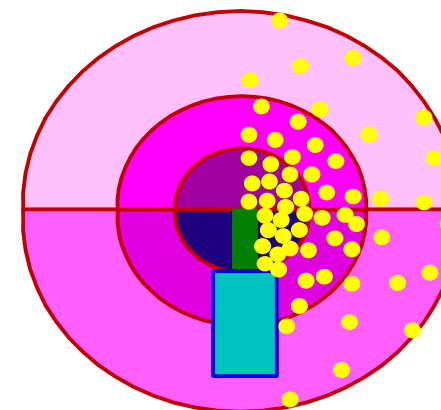
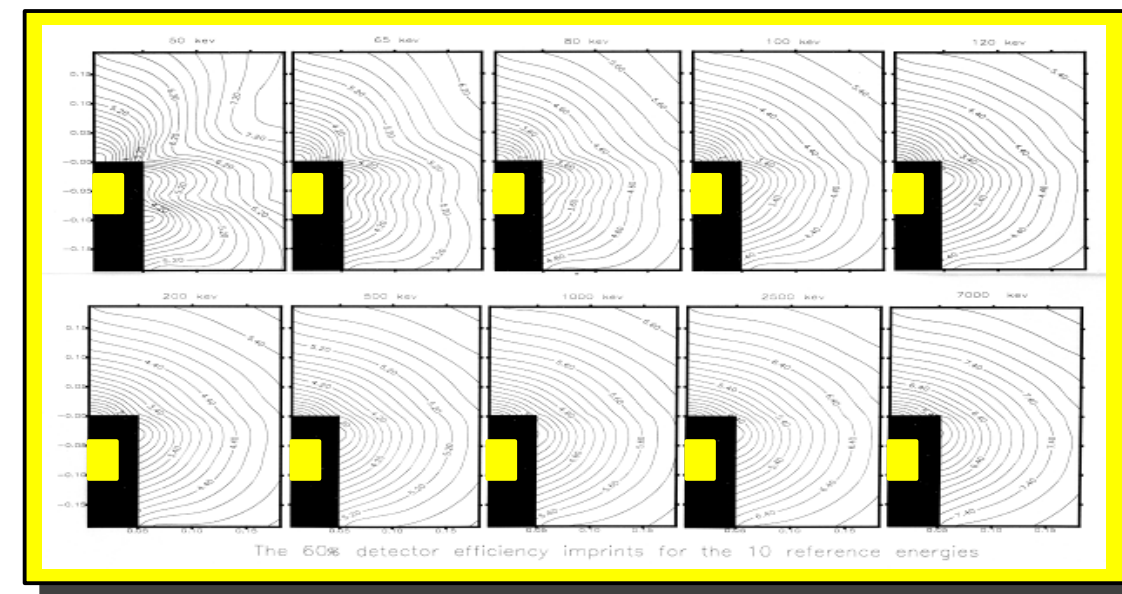
- NIST-traceable multi-energy sources
 - Point ^{241}Am , ^{152}Eu sources
 - Disc mixed gamma source
- Counted at 8 locations
 - Designed to determine important unknown detector parameters
- Use mechanical jig to assure precise geometry
- Use standardized factory electronics





Detector Characterization – Monte Carlo Modeling

- Detailed MCNP model of detector created
 - About 30 dimensional parameters
 - Populated by manufacturing dimensions
- Efficiency for each of the 8 source geometries computed with MCNP
 - Compared to measured efficiency
 - MCNP model key parameters adjusted so efficiency matches measured
 - Diameter, height, setback, dead layer [front, side, back]





Detector Characterization – Lookup Table

- Validated MCNP model used to compute efficiency at 800 spatial locations
 - High density where efficiency varies rapidly
 - Radial symmetry assumed
- Gridding process used to interpolate efficiency between modeled points
- Efficiency parameters incorporated into supplied Detector Characterization file used by ISOCS/LabSOCS software to create in-vacuo efficiency at each voxel point
 - 0 mm to 500 m distance
 - all directions - front, side, back
 - 45 keV - 7000 keV

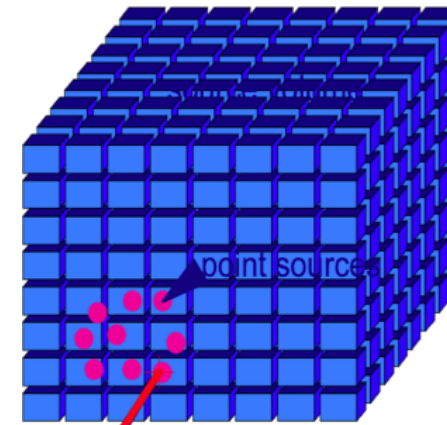


ISOCS Efficiency Determination

ISOCS is a user-interface to an engine that evaluates a numerical integral

- Users specify the geometry (i.e. detector, container, materials)
- The ISOCS software breaks the radioactive portion of the geometry into “voxels”
 - Each voxel is treated as a point source
 - The efficiency for the point source is obtained from the characterization file (i.e. lookup table) modified by attenuation through all materials between the source and the detector

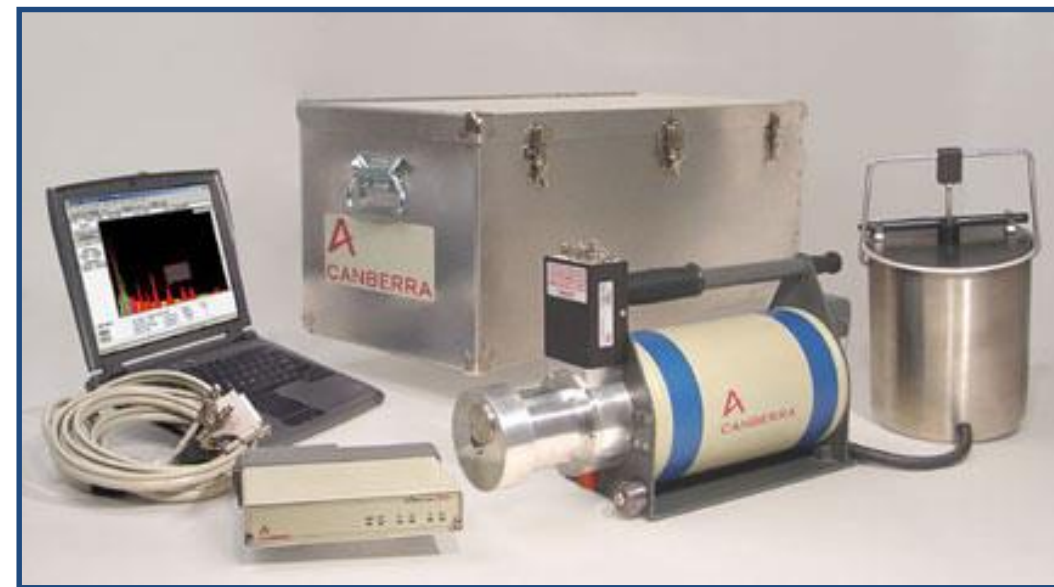
$$\varepsilon_{ISOCS} = \sum_{\text{voxels}} \varepsilon_{\text{character.pt}} \cdot \text{attenuation}$$





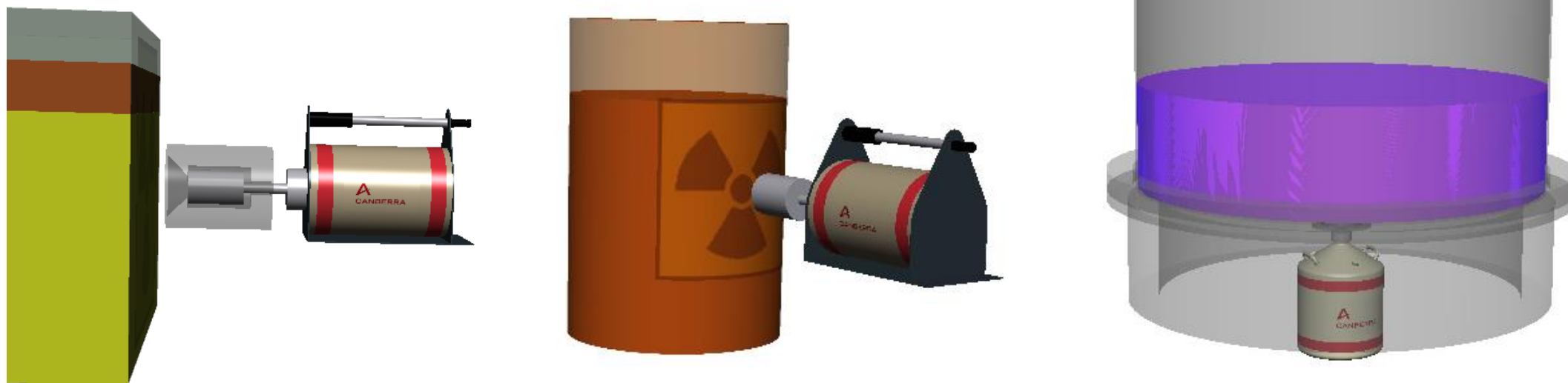
Hardware Configuration

- ISOCS is traditionally used with HPGe detectors
 - Factory characterized (specific characterization)
 - Regular detector (generic characterization)
- NaI detector characterizations are also available
- Multi-channel analyzer
- Computer with Genie-2000 software





ISOCS Models



Almost any object likely to be encountered in the laboratory or the field can be adequately modeled using one of the ISOCS standard geometry templates

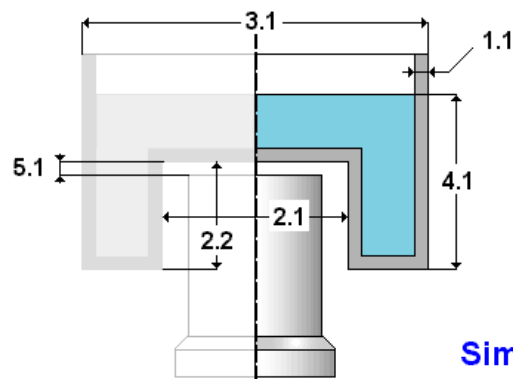
Using ISOCS Templates

- Each template has a worksheet where operator can specify necessary physical dimensions of the object
- Each template has a reference plane and reference point that allows to specify detector position relative to the object
- Environmental conditions are important for lower energies and long distances
- Chemical composition and densities of the container and matrix must be specified

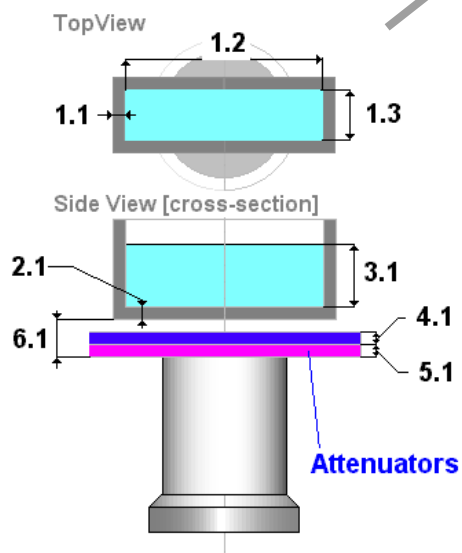


Geometry Description

Simplified Marinelli Beaker

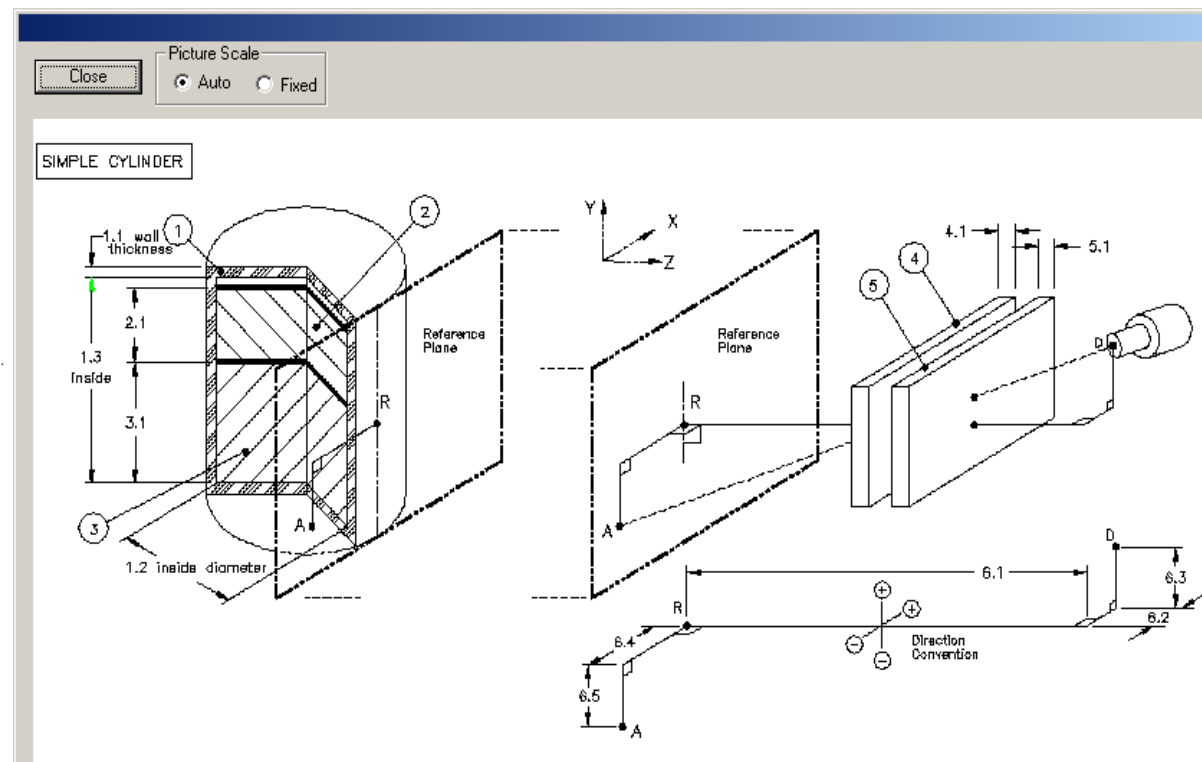


Simplified Box



Geometry
Composer

Geometry
Description
(*GEO)





Inputting Parameters

ISOCS, Template: SIMPLE_CYLINDER

Delete Help

Template Version: default
Save Data As User Version

Detector and End-Cap: none
Diam. 0 Length
Dimensions Scale: ☐ mm ☒ cm ☐ inch ☐ foot ☐ m

Geometry Information
Description: none
Comment: none

Edit Additional Equipment
Collimator: none Edit
Housing: none Edit

OK
Cancel
Help
Show Template

Geometry Elements

| # | Description |
|---|------------------|
| 1 | Container |
| 2 | Source-Top Layer |
| 3 | Source-Bot Layer |
| 4 | Absorber1 |
| 5 | Absorber2 |
| 6 | Source-Detector |

Dimensions

| d.1 | d.2 | d.3 | d.4 | d.5 |
|-----|-----|-----|-----|-----|
| 0 | 0 | 0 | | |
| 0 | | | | |
| 0 | | | | |
| 0 | | | | |
| 0 | | | | |
| 0 | 0 | 0 | 0 | 0 |

RelConc: 0
Density and Material

| g/cm3 | Material |
|-------|----------|
| 0 | none |
| 0 | none |
| 0 | none |
| 0 | none |
| 0 | none |

Select from List
Call MuEditor:

- 304ss
- acrylic
- aluminum
- cellulos
- concrete
- copper
- csteel
- dirt1
- dirt2
- dirt3
- dirt4
- dryair
- drydirt
- epoxy
- germanum
- glass
- hdepoxy
- hpolyeth
- iron

Close
Picture Scale: ☒ Auto ☐ Fixed

SIMPLE CYLINDER

**Generic Detector
Characterizations**

Detector and End-Cap

Example

Example

- Dia=45mm_Coaxial
- Dia=50mm_Coaxial
- Dia=55mm_Coaxial
- Dia=60mm_Coaxial
- Dia=65mm_Coaxial
- Dia=70mm_Coaxial
- Dia=75mm_Coaxial
- Dia=80mm_Coaxial
- Dia=90mm_Coaxial
- Dia=60mm_Planar
- Dia=70mm_Planar
- Dia=80mm_Planar
- 8509

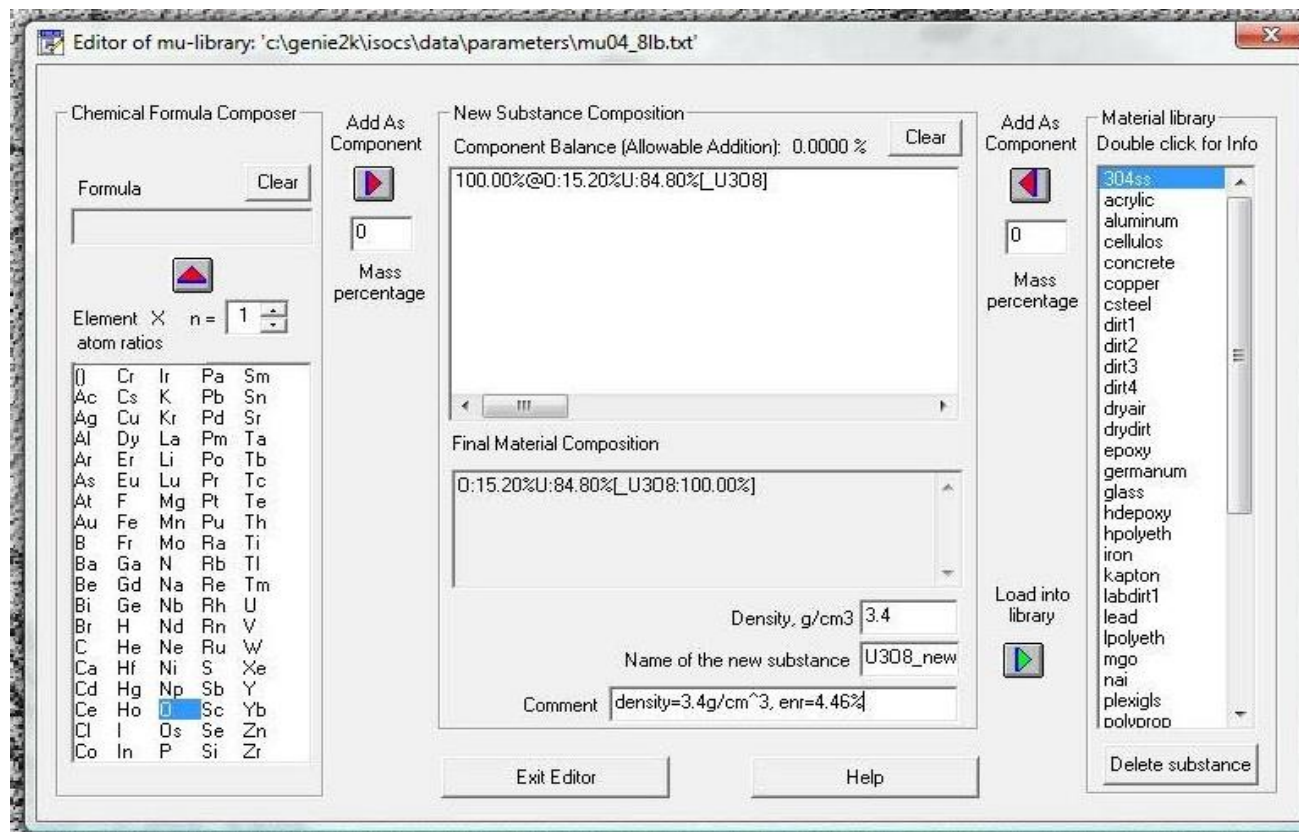
**Detector with serial number
8509**



Mu-Library Editor

Mu-library contains a variety of materials and compounds

- Additional materials can be created and added





Geometry Composer Report

Once model is complete:

- Check geometry validity
- Verify efficiency parameters
- Adjust environmental conditions

Edit Environment

Temperature: ☒ Celsius ☐ Fahrenheit ☐ Kelvin
Value:

Pressure: ☒ mm Hg ☐ Atmosphere
Value:

Relative humidity, %

Untitled * - GeomComposer

File Edit Efficiency Curve View Options Help

Geometry Composer Report

Date: Thursday, November 12, 2009
Description: simple_cylinder
Comment: example
File Name: (new geometry: no file name yet)
Software: ISOCS
Template: SIMPLE_CYLINDER, Version: default
Detector: 7781
Environment: Temperature= 22 C, Pressure= 760 mmHg
Integration: Convergence= 1.00%, MDRPN= 2^(4) CRPN=

| # | Geometry Compon. | d1 | d2 | d3 | d4 |
|---|------------------|--------|-------|-------|-------|
| 1 | Container | 2.00 | 70.00 | 96.00 | |
| 2 | Source-Top Layer | 5.00 | | | |
| 3 | Source-Bot Layer | 20.80 | | | |
| 4 | Absorber1 | 3.00 | | | |
| 5 | Absorber2 | | | | |
| 6 | Source-Detector | 165.00 | 11.00 | 5.00 | 11.00 |

Dimensions (mm):

List of energies for efficiency curve generation:
100.0 150.0 200.0 300.0 500.0 700.0 1000.0

Parameters controlling efficiency curve generation

Energy list | Integration

Energy interval is 45.0 - 7000.0 (defined by DCG)

| Energy, keV | Error, % |
|-------------|----------|
| 100.00 | 10.0 |
| 150.00 | 10.0 |
| 200.00 | 8.0 |
| 300.00 | 8.0 |
| 500.00 | 6.0 |
| 700.00 | 6.0 |
| 1000.00 | 4.0 |
| 1400.00 | 4.0 |
| 2000.00 | 4.0 |

Manual editing: Energy, keV Error, %

Files:

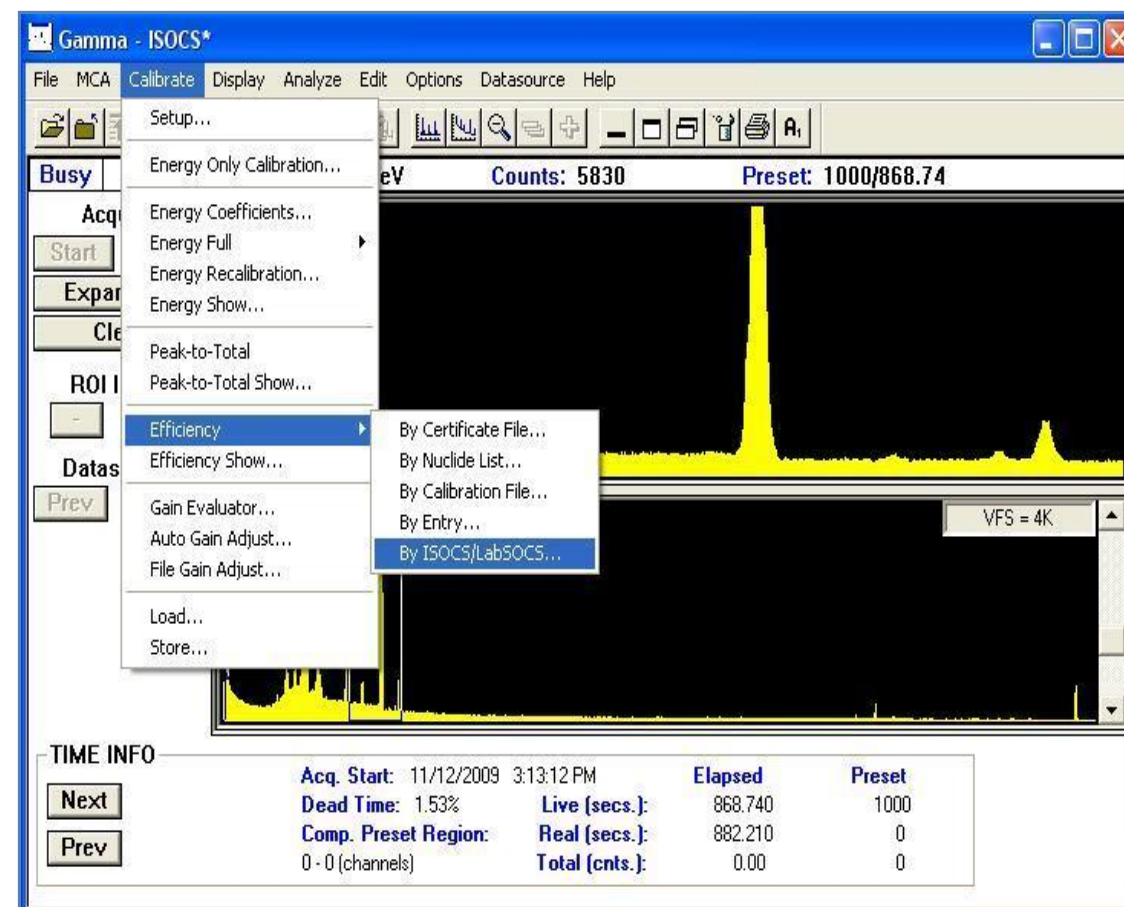
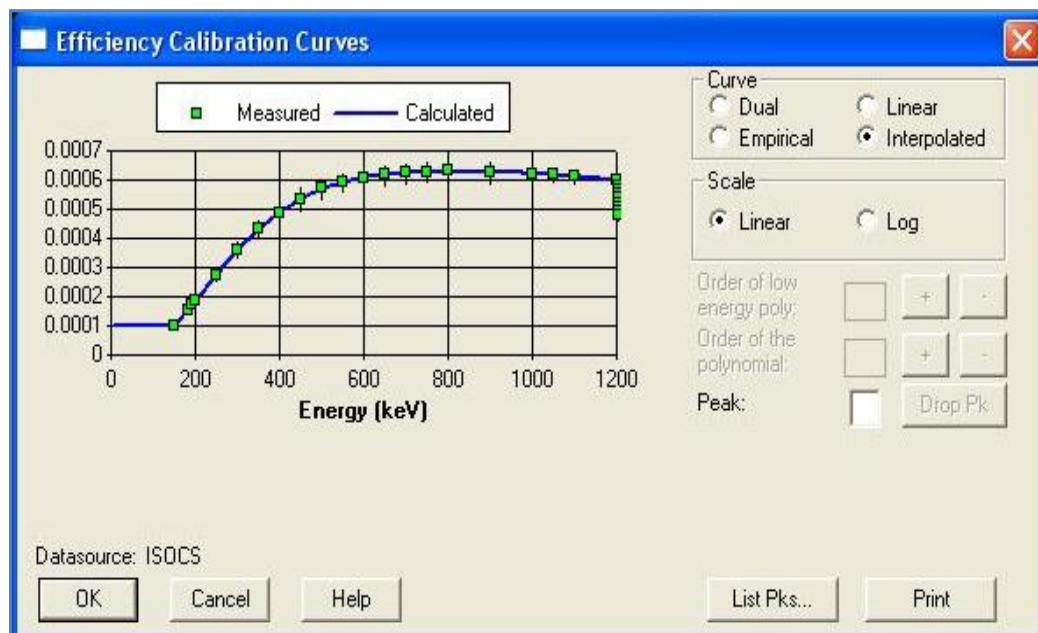
SIMPLE CYLINDER



Efficiency Calibration in Genie

Next step is generating efficiency calibration curve in Genie-2000 software

- Choose curve type
- Store efficiency calibration file



Creating a Report

- Variety of reporting options available
 - Genie-2000 allows for creating custom reports or modifying existing
- Example of the report showing both activity and mass of nuclear material

File: ISOCS
NID Library: C:\GENIE2K\CAMFILES\U_only_shurus.NLB
Efficiency Calibration: SIMPLE_EXAMPLE

Sample ID: Sample title. Operator: _____
Analysis performed: 11/12/09 3:33:42

| No | Isotope | Activity, uCi | Mass, Gram | Uncertainty, % | Comment |
|----|---------|------------------|---------------|-------------------|---------|
| 1 | U-235 | 20.14 | 9.59 | 0.49 | |
| 2 | U-238 | 55.67 | 165.91 | 0.95 | |

Analyzed by: _____ Reviewed by: _____

ISOCS Performance

The accuracy of ISOCS will be dependent on

- How well known the geometry and composition of the NM is
- How well known the geometry and composition of interviewing material is
- How closely the modeled geometry matches the measurement configuration

For large quantities of NM material that are self attenuating, ISOCS can only confirm the material that can be seen

ISOCS Summary

- ISOCS is a sophisticated system for mathematical efficiency calibration and quantification of radioactive material
 - No calibration source required
 - Capabilities limited to the number of templates
- ISOCS can be used for many problems, from characterization of small samples in the laboratory, to process holdup in facility, to waste containers, to environmental surveys

What is SNAP™?

- ▶ SNAP = Spectral Nondestructive Assay Platform
 - A point-kernel modeling routine
 - A product of *Pajarito Scientific Corporation*
- ▶ Analyzes gamma ray data from other vendor's detection systems (adaptable to what you already own)
- ▶ Detector intrinsic efficiency and angular response determined empirically with NIST traceable sources
- ▶ Quantifies any gamma emitting radiation source
 - Assay results include activity and concentration
 - Mass for SNM

SNAP™ Applications

- ▶ Developed in the 1990's primarily as a means to assay a huge variety of waste materials at LANL
- ▶ Additional features were added based on need
- ▶ Can also do laboratory measurement analyses on
 - Small samples
 - Holdup measurements
 - Area sources
- ▶ Not recommended for “infinite plane” area source (e.g., Fukushima)
- ▶ Not recommended for U or Pu samples whose thickness is beyond “infinite” for gammas

Quantifying Source Activity or Mass



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$$Activity(Bq) = \frac{Net\ cps}{G \cdot EI \cdot Y \cdot SA}$$

$$Mass(g) = Activity \cdot \frac{T_{1/2}}{\ln 2} \cdot \frac{A}{6.022E + 23}$$

G: geometry or solid angle correction for source-detector distance

E_i: intrinsic detection efficiency at that gamma ray energy

Y: yield (branching ratio) for specific gamma ray

SA: sources of attenuation (external shields and self absorption)

T_{1/2}: half life of the nuclide emitting that gamma ray

A: atomic mass of this nuclide

Typical Waste Drum Setup

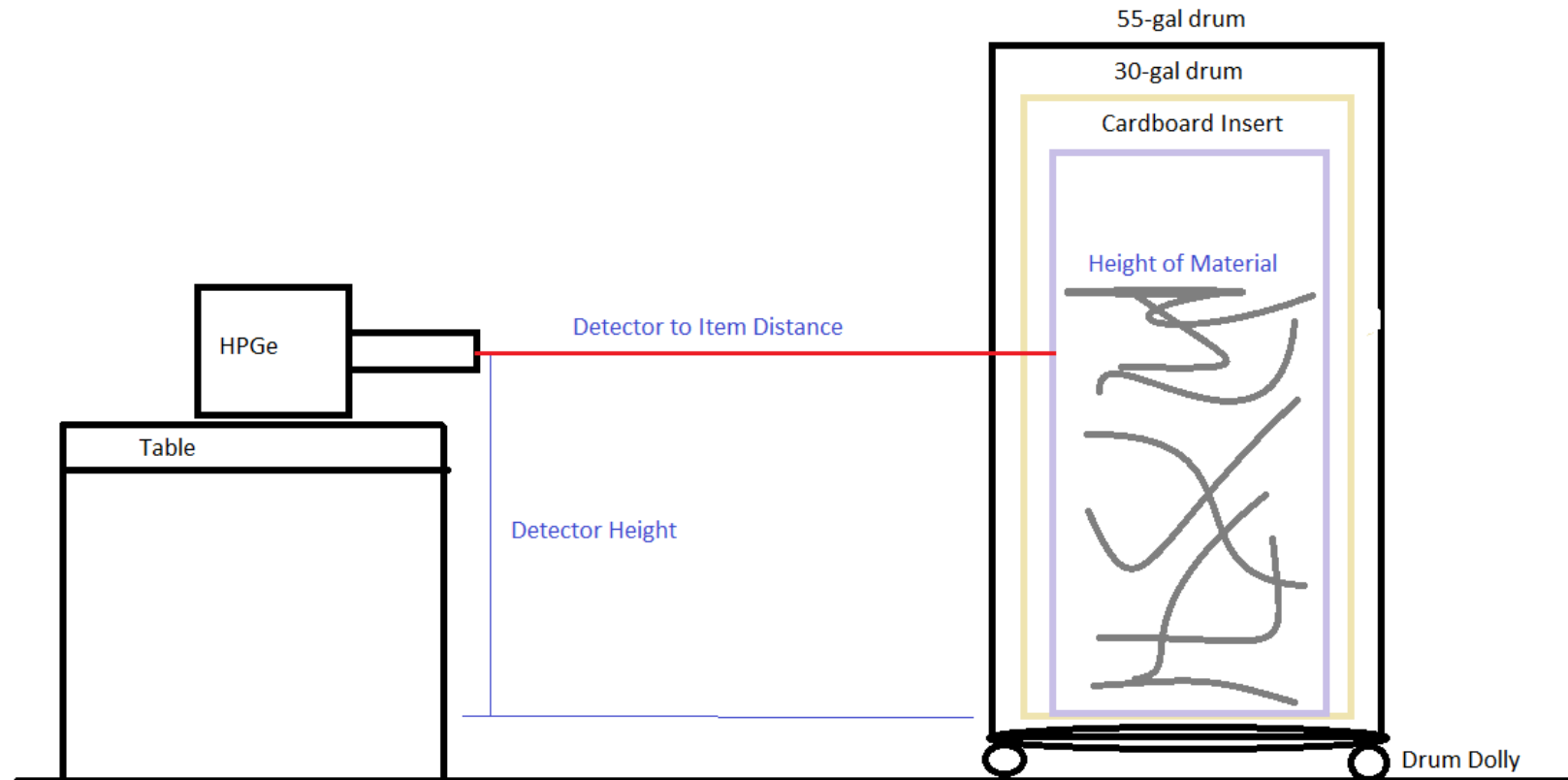


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Detector Solid Angle Fraction

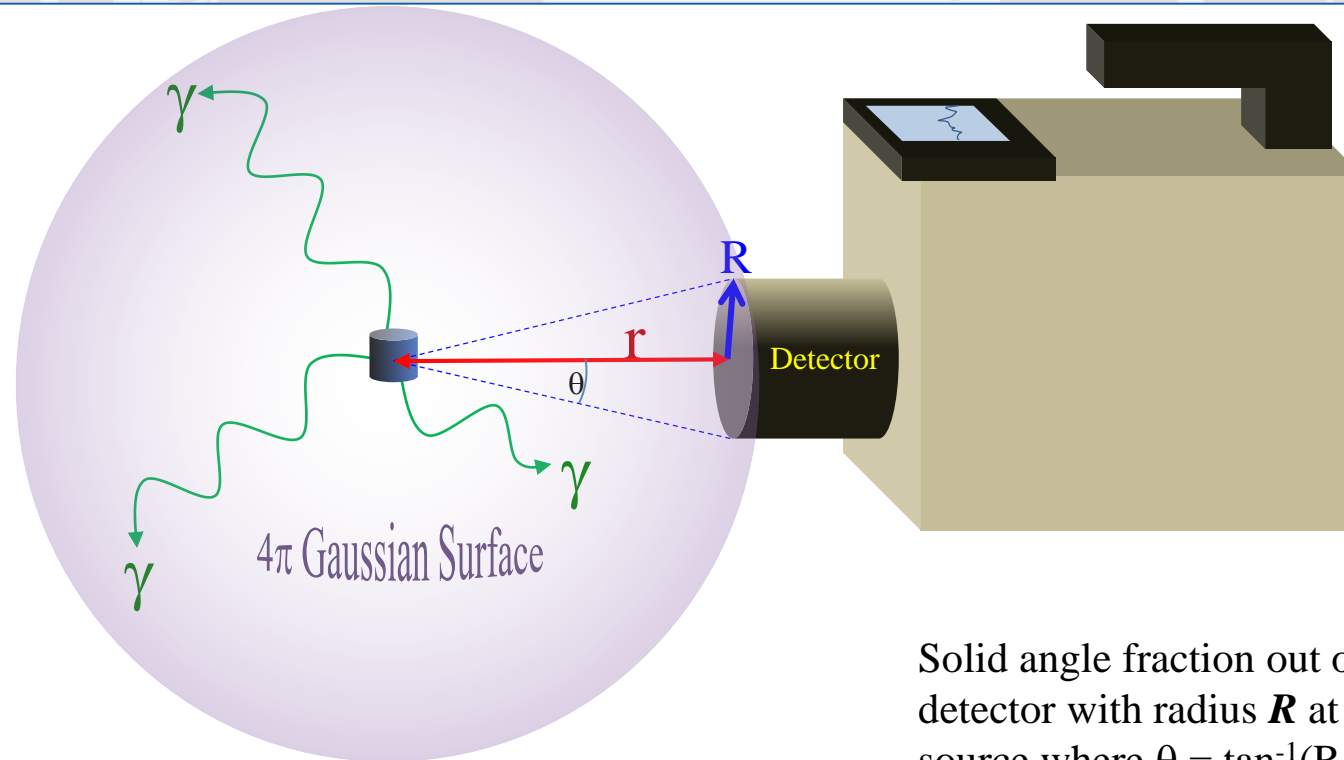


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Solid angle fraction out of 4π steradians for a detector with radius R at a distance r from the source where $\theta = \tan^{-1}(R/r)$:

$$\frac{\Omega}{4\pi} = \frac{1}{2}(1 - \cos \theta)$$

Detection Efficiency

- SNAP uses the detector intrinsic efficiency (E_I) in calculations
- The intrinsic response is fairly constant over a large range of conditions (but not all)

$$\mathcal{E}_I = \frac{\text{number of events recorded}}{\text{number of photons incident}}$$

Typical Intrinsic Efficiency for HPGe Detector – limited range



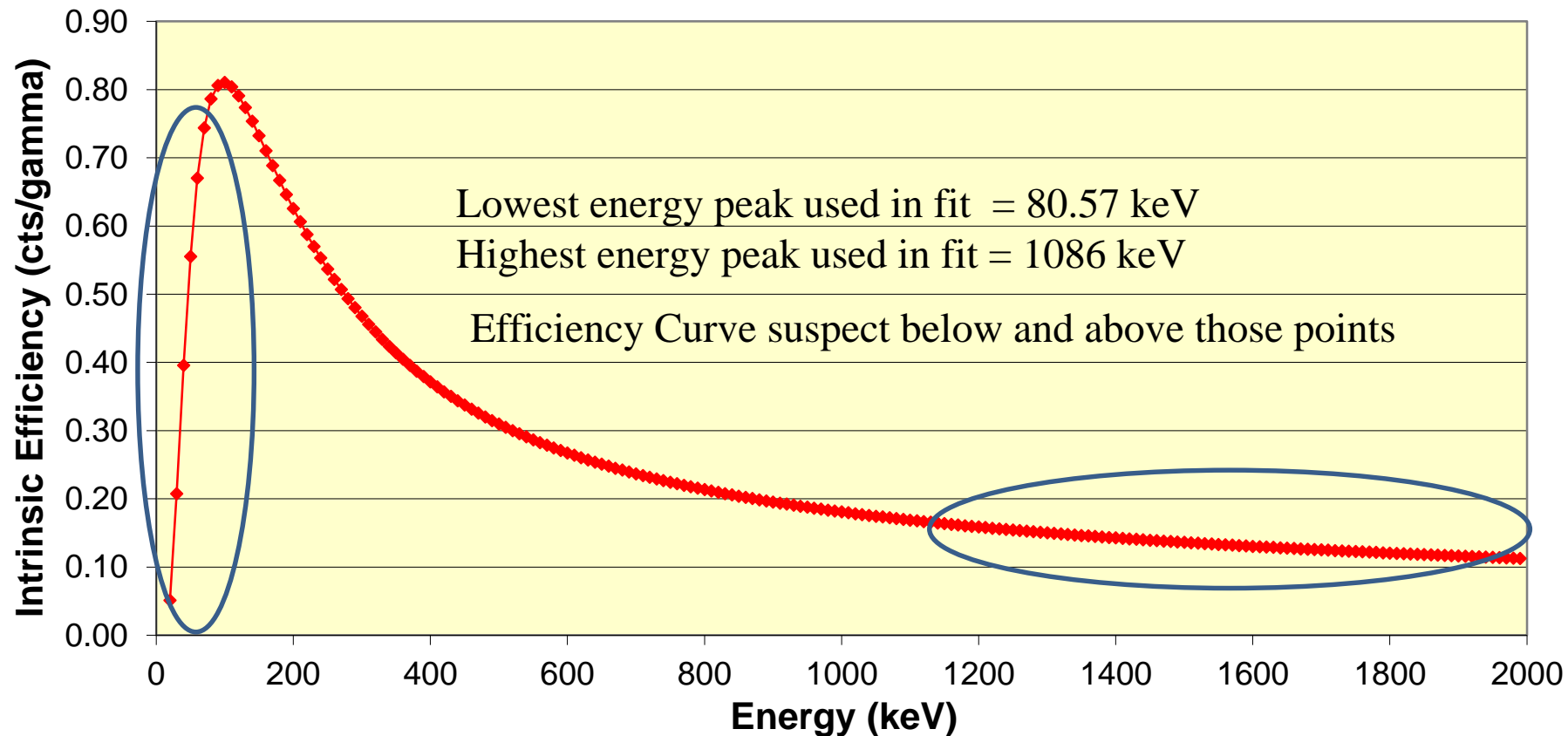
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SNAP Efficiency Calibration for HPGe Detector



Intrinsic Efficiency Can Vary with Distance

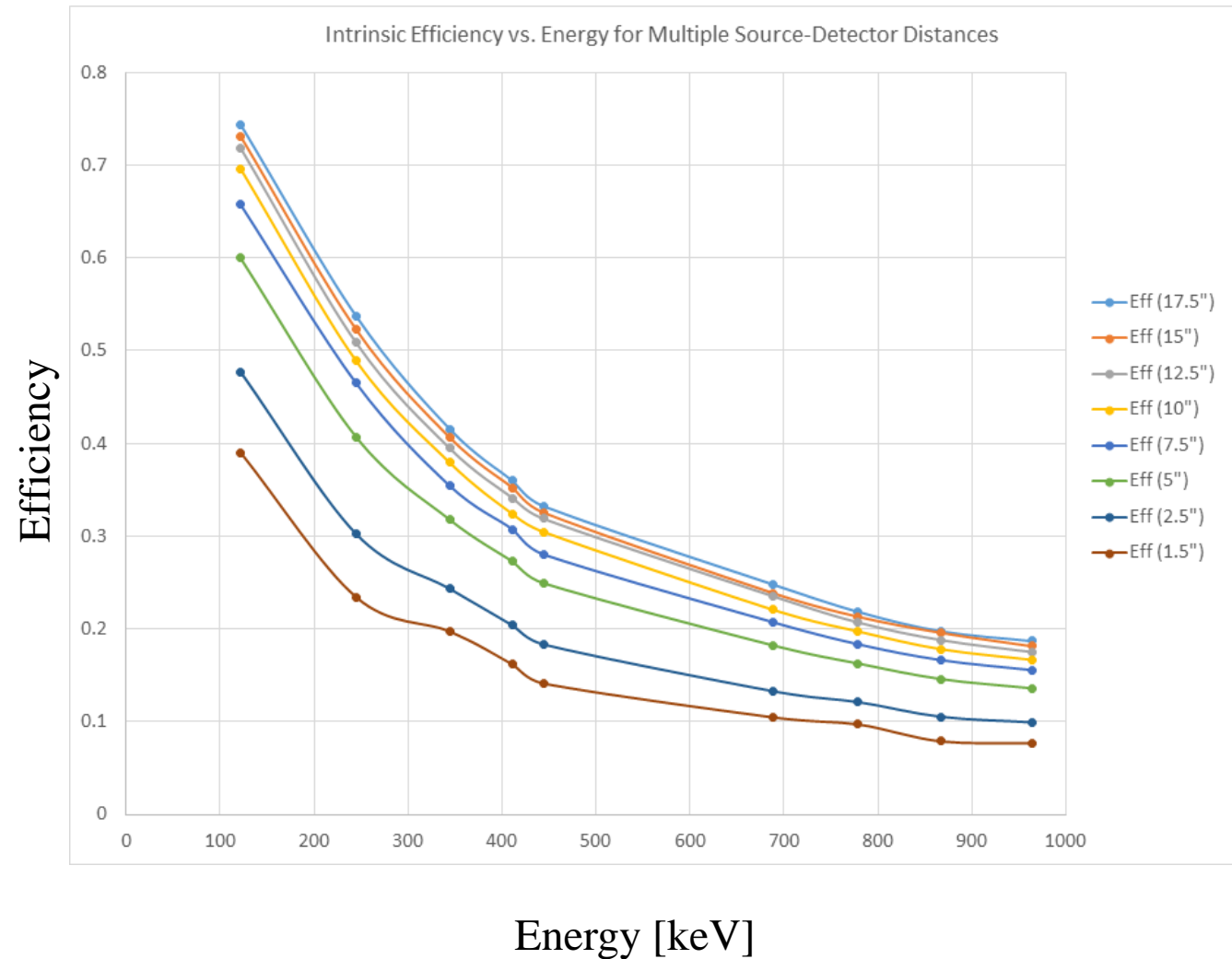


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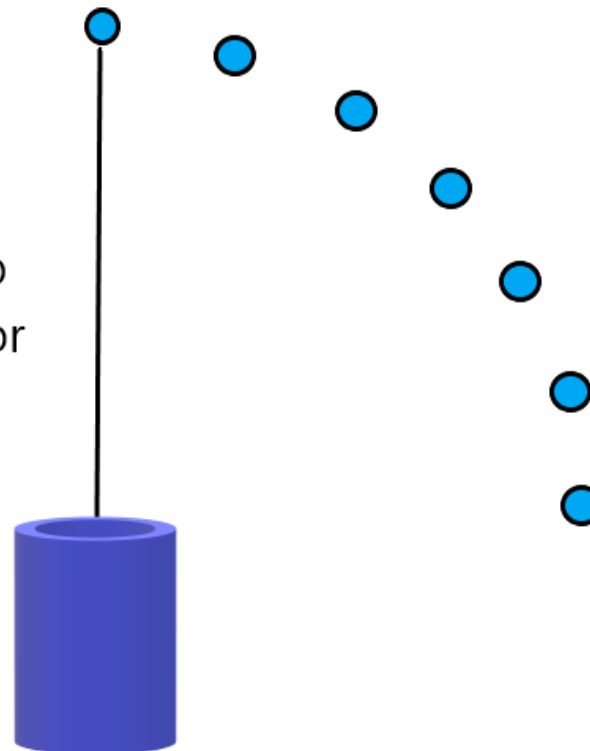
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SNAP Corrects for Angular Response



9 measurements at 10 degree increments at 1 meter are taken to determine the angular response for offnormal source locations



Collimated Detector: Efficiency as a Function of Transverse Angles

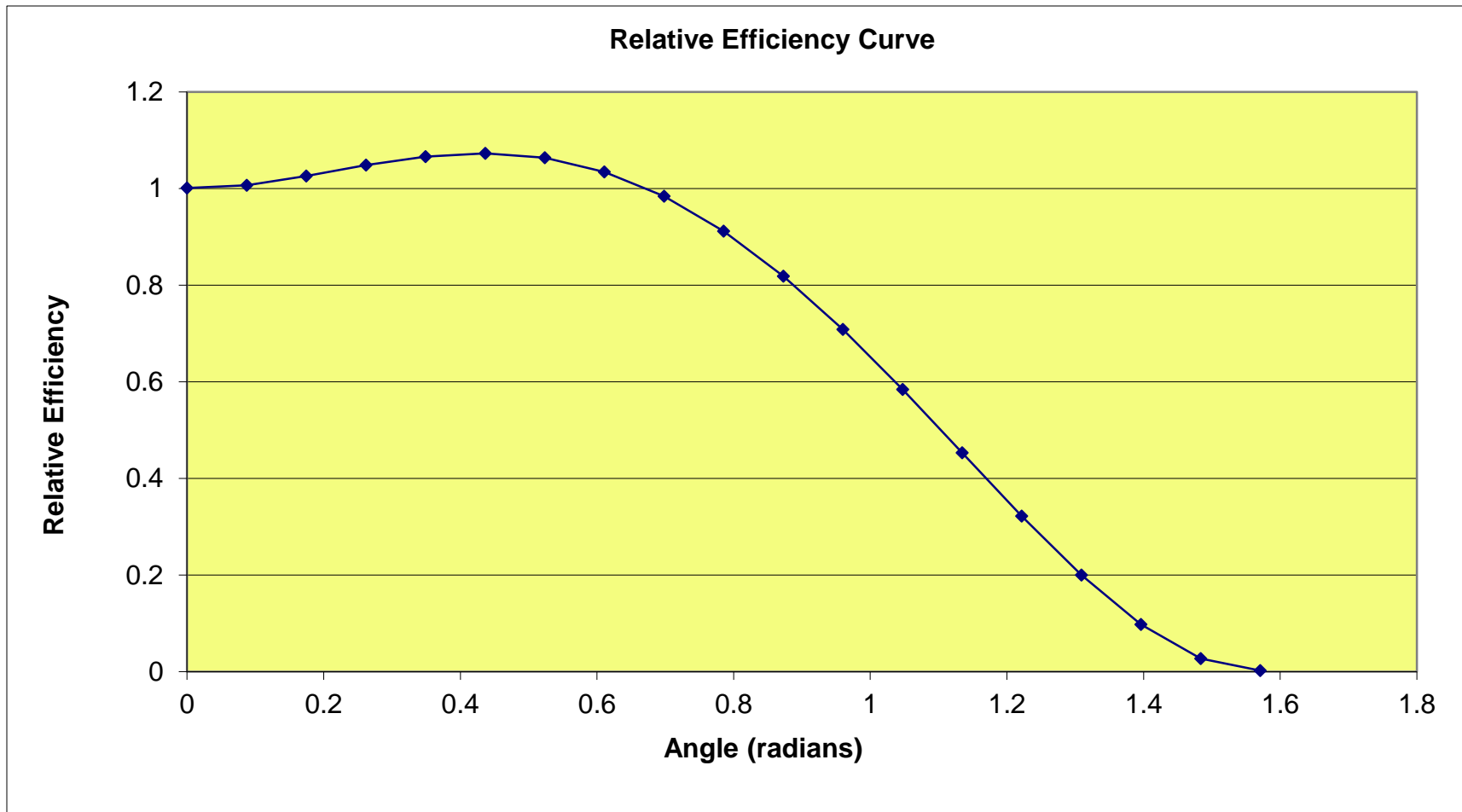


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Attenuation Corrections in SNAP

- Attenuation losses are a function of:
 - Materials in path of gammas
 - Inherent density of those materials
 - How the materials are dispersed in the volume of the sample container
 - thus, the effective density of the sample material
 - Energy of the gamma ray
- SNAP calculates Mass Attenuation Coefficients for each gamma ray used in the calculations

Shielding Materials and Energy Relationship

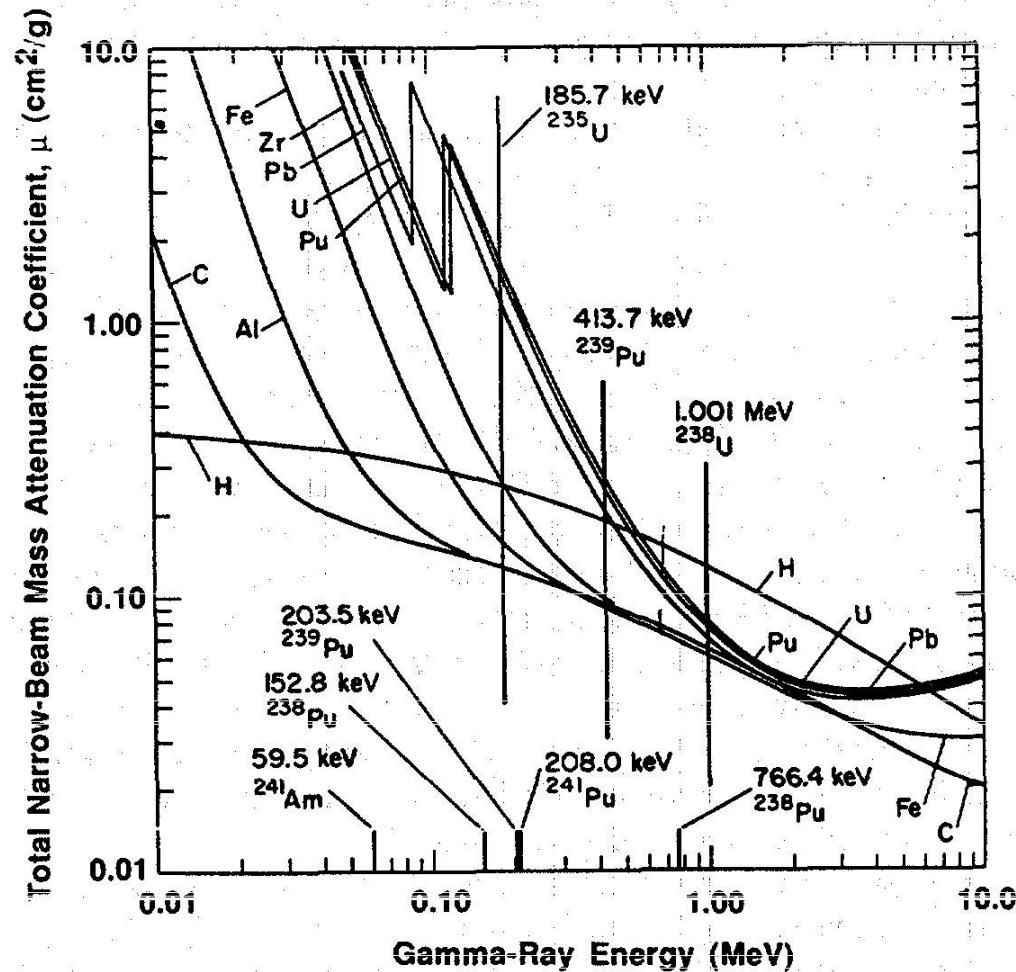


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Example of Mass Attenuation Fits



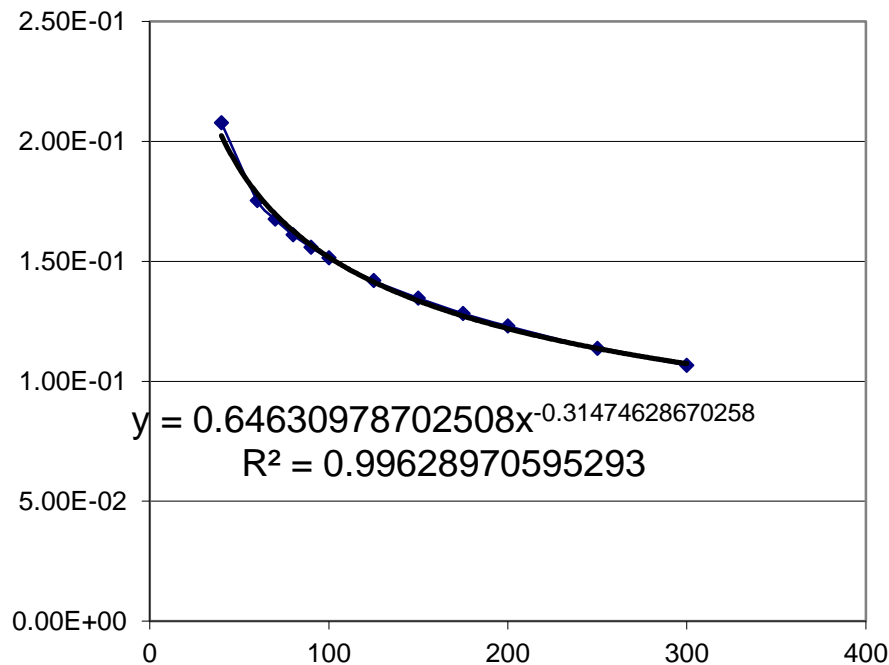
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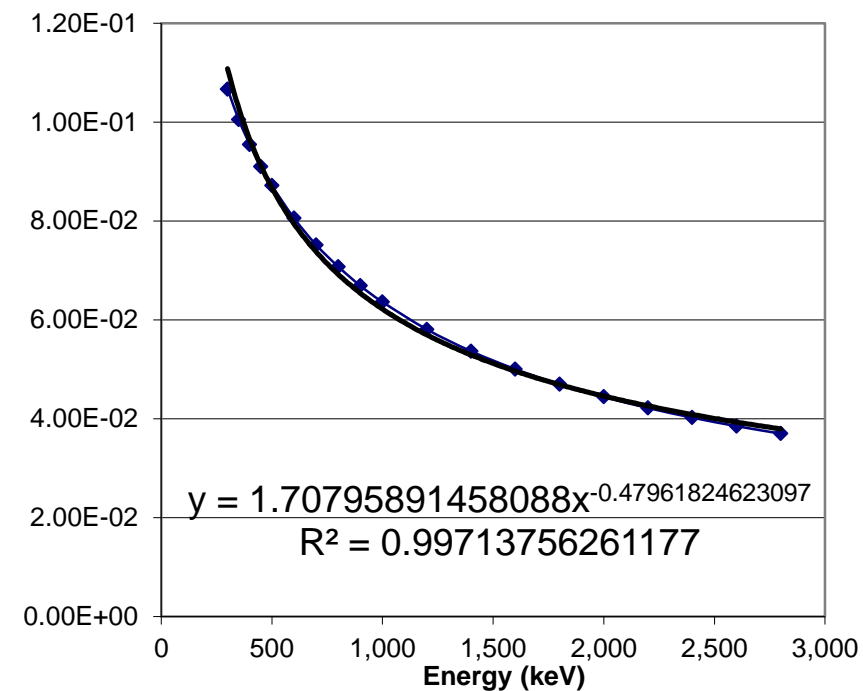


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Mass Attenuation Fit for Carbon (Graphite)



Mass Attenuation Fit for Carbon (High Energy)



SNAP's 4 Step Process

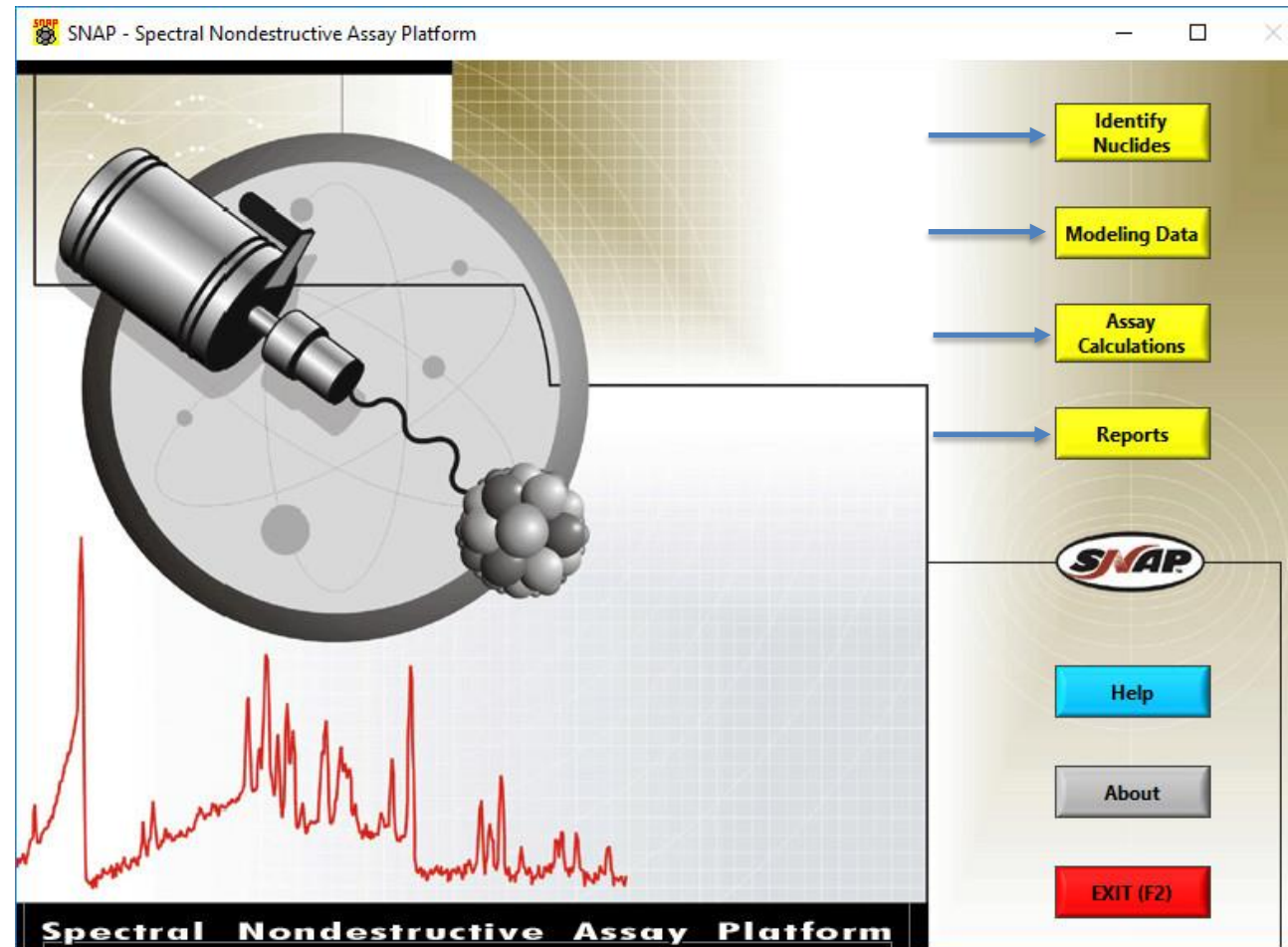


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Process Step 1: Identify Nuclides (Library Driven)



Identify Nuclides

Report File Type
Peak Doctor
Genie2k Spectrum
Genie2k Background
Genie2k ROI

Search for Report File

Report File Name
11190602.prn

Load from Report File

Load Custom Full Library

Currently Loaded Library
Library.txt

Edit Custom Full Library

Sub Libraries
Full
NORM FULL *(Library)*
BKG NORM *(Library)*
TRU Nuclides *(Library)*
Auto TRU *(Library)*
Pu238/Heat Source *(Library)*
Uranium *(Library)*
Activation/Spallation *(Library)*
Pa231 Series *(Library)*
U233 *(Library)*
Calibration Sources *(Library)*
Medical Nuclides *(Library)*

Input Data
Analysis Report for Peak Doctor Version Version 1.0.0
Date of analysis: Nov 19, 2006
RobWin has to be here as a token string for SNAP.
Detector Calibration: Tweety
Spectrum ID: 11190602
Analysis Energy Range: 40.151keV to 2000.0keV

| Egy (keV) | FWHM | Area | +/-Area | Background |
|-----------|-------|--------|---------|------------|
| 59.55 | 0.710 | 100828 | 346.4 | 4795.1 |
| 94.64 | 0.905 | 2408 | 112.6 | 2565.3 |
| 97.14 | 0.907 | 2559 | 110.4 | 2409.7 |
| 98.86 | 0.909 | 21363 | 174.4 | 2265.0 |
| 100.87 | 0.911 | 3346 | 108.1 | 2082.9 |
| 102.91 | 0.912 | 21031 | 169.3 | 1909.8 |
| 106.10 | 0.858 | 427 | 83.4 | 1632.1 |
| 110.29 | 0.804 | 813 | 83.2 | 1528.0 |
| 111.25 | 0.805 | 1397 | 86.9 | 1539.7 |
| 122.99 | 0.862 | 1968 | 93.3 | 1682.2 |
| 125.27 | 0.799 | 8063 | 118.2 | 1479.4 |
| 129.28 | 0.820 | 5839 | 103.8 | 1233.3 |
| 144.09 | 1.095 | 482 | 85.0 | 1685.6 |
| 146.51 | 1.109 | 1665 | 91.0 | 1653.9 |
| 148.59 | 0.848 | 758 | 75.1 | 1222.1 |
| 152.71 | 0.933 | 1437 | 80.9 | 1275.5 |
| 160.28 | 0.467 | 142 | 53.0 | 667.5 |
| 169.56 | 0.853 | 615 | 71.6 | 1129.1 |
| 185.83 | 0.883 | 410 | 67.8 | 1048.2 |
| 203.54 | 0.863 | 893 | 67.6 | 919.6 |
| 208.04 | 0.894 | 5151 | 94.9 | 965.7 |
| 228.19 | 0.865 | 636 | 58.6 | 699.2 |
| 238.65 | 0.931 | 6043 | 93.4 | 668.8 |
| 241.08 | 1.247 | 506 | 63.1 | 868.0 |
| 277.55 | 0.938 | 1082 | 55.9 | 509.4 |
| 300.15 | 0.923 | 2315 | 64.2 | 451.0 |

Energy Calibration
Energy Calibration On

Real Energy Spectrum Energy
59.54 : Am241 59.550
1460.83 : K40 1460.810

Identify Peaks (F4)

Reset (F12)

Reset BGn File

Bkg Subtract

Save to RPu File

Modeling Data (F1)

Return (F2)

Edit Sub Libraries

Search Options
☒ Exclusive ☐ Falthrough ☒ Semi-Automated Mode ☒ Fully-Automated Mode

Energy Match Tolerance (keV) 0.5

Step 2: Enter Modeling Information



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Modeling Data

| | | | |
|-----------------------------|---------------------------|-----------------------------|-----------------|
| Description | TA50 Caustic Tank | Length/Weight Units | English |
| File ID | 11190602.RPu | Activity Units | Ci |
| | Search for File | Concentration Units | nCi/g |
| Custom WF | Empty Drum | | |
| | Choose/Edit Custom Models | | |
| Model Type | Cylinder | Primary Wall Thickness | 0.280000 (in) |
| Height | 96.00 (in) | Primary Wall Material | Stainless Steel |
| Diameter | 96.00 (in) | Secondary Wall Thickness | 0.000000 (in) |
| N/A | 0.06 (in) | Secondary Wall Material | None |
| Angular Limit (Deg) | 45.00 | Tertiary Wall Thickness | 0.000000 (in) |
| Detector to Item Distance | 48.00 (in) | Tertiary Wall Material | None |
| Detector Height | 12.00 (in) | | |
| Left of Center | 0.00 (in) | Count Time (sec) | 1800 |
| Detector Calibration | Tweety | Altitude | 7000.00 (ft) |
| Angular Correction | Tweety: Scooby @356 | Detection Limit | MDA |
| Primary Matrix Fraction (%) | 100.00 | Rate Loss Correction Factor | 1.000 |
| Primary Matrix Material | Air | GA Error #Sides | 2 Sides |
| Secondary Matrix Material | Air | | |
| Matrix Weight | 24.875 (lbs) | Analyst | Steve Myers |
| Item Weight | 5000.00 (lbs) | | |

Reset Data (F12)

Edit Detector Calibration

Edit Materials

Note: Last setup is automatically loaded as default.

Save and load setup allows you to save and recall commonly used setups.

Save Custom Setup

Load Custom Setup

Assay Calculations (F1)

Return (F2)

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[illegible]

Step 4: Finalize Reports



Reports

Item

TA50 Caustic Tank

File ID

11190602.RPu

Type

Cylinder

Height

96.00 (in)

Diameter

96.00 (in)

Diameter

0.06 (in)

Volume

402.12 (ft³)

Detector Location

Distance

48.00 (in)

Height

12.00 (in)

Left of Center

0.00 (in)

Detector

Tweety

Waste Matrix

Air

Waste Matrix Density

(g/cm3) 9.909E-4

Package Weight

(lbs)

24.87

Item Weight

(lbs)

5000.00

Waste Matrix Eff. Density

(g/cm3)

9.910E-4

Wall Thickness

Primary

0.280000 (in)

Secondary

0.000000 (in)

Tertiary

0.000000 (in)

Wall Material

Primary

Stainless

Secondary

None

Tertiary

None

Wall Material Density (g/cm3)

Primary

7.840E+0

Secondary

0.000E+0

Tertiary

0.000E+0

GA Error #Sides

2 Sides

Count Time

(sec)

1800

Altitude

(ft)

7000.00

Rate Loss

Correction Factor

1.000

Lump Correction

None

Thickness (microns)

0

Summary:

| Nuclide | Uniform Activity (Ci) | Uniform Conc (nCi/g) | Uniform SNM mass (g) | +2s Error (%) |
|---------|-----------------------|----------------------|----------------------|---------------|
| Am241 | 6.13E-1 | 2.70E+2 | 1.79E-1 | 106.45 |
| Pu238 | 3.36E-1 | 1.48E+2 | 1.96E-2 | 147.10 |
| Pu239 | 2.71E-1 | 1.19E+2 | 4.36E+0 | 112.10 |
| Pu240 | 6.22E-2 | 2.74E+1 | 2.74E-1 | 165.61 |
| Pu241 | 9.20E-1 | 4.06E+2 | 8.93E-3 | 150.49 |
| U235 | < 1.21E-6 | < 5.32E-4 | < 5.59E-1 | 131.41 |

Notes:

Net counts displayed are equivalent to the detection limit.

☐ Edit Error Estimates

Uniform Distribution (push for Weighted)

Add More Results?

☒ Include RPu?

Print Report (F4)

Save Report

Calculate FGE

View Errors

Return (F2)

Return to Home (Esc)

Detail:

* Indicates that energy is out of detector calibration range

| Nuclide | Energy (keV) | Yield (gps/dps) | Net Counts (counts) | Bkg Counts (counts) | Intrinsic Efficiency (cps/gps) | Activity (Ci) | MDA (Ci) | Conc (nCi/g) | MDA | SNM mass (g) | +2s Error (%) |
|---------|--------------|-----------------|---------------------|---------------------|--------------------------------|---------------|----------|--------------|---------|--------------|---------------|
| Am241 | 125.29 | 4.14E-5 | 8063 | 2958 | 6.163E-1 | 6.34E-1 | 2.01E-2 | 2.80E+2 | 8.88E+0 | 1.85E-1 | 168.39 |
| Am241 | 721.99 | 1.89E-6 | 481 | 154 | 2.500E-1 | 5.91E-1 | 7.46E-2 | 2.61E+2 | 3.29E+1 | 1.72E-1 | 106.45 |
| Pu238 | 152.68 | 9.37E-6 | 1437 | 2550 | 6.199E-1 | 3.36E-1 | 5.57E-2 | 1.48E+2 | 2.45E+1 | 1.96E-2 | 147.10 |
| Pu239 | 129.30 | 6.29E-5 | 5839 | 2466 | 6.192E-1 | 2.81E-1 | 1.13E-2 | 1.24E+2 | 4.96E+0 | 4.53E+0 | 164.40 |
| Pu239 | 375.05 | 1.55E-5 | 2525 | 456 | 4.040E-1 | 2.80E-1 | 1.13E-2 | 1.23E+2 | 4.99E+0 | 4.51E+0 | 113.78 |
| Pu239 | 413.71 | 1.47E-5 | 2088 | 368 | 3.767E-1 | 2.52E-1 | 1.11E-2 | 1.11E+2 | 4.90E+0 | 4.06E+0 | 112.10 |
| Pu240 | 160.28 | 4.09E-6 | 125 | 1334 | 6.160E-1 | 6.22E-2 | 8.60E-2 | 2.74E+1 | 3.79E+1 | 2.74E-1 | 165.61 |
| Pu241 | 148.57 | 1.89E-6 | 758 | 2444 | 6.213E-1 | 9.20E-1 | 2.83E-1 | 4.06E+2 | 1.25E+2 | 8.93E-3 | 150.49 |
| U235 | 185.74 | 5.72E-1 | 407.309 | 7560 | 5.947E-1 | < 1.21E-6 | 1.21E-6 | < 5.32E-4 | 5.32E-4 | < 5.59E-1 | 131.41 |

Verification Results: PDP Challenge



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**Performance
Demonstration
Project Drums with
various matrices used
to certify WIPP
assay systems**



Point sources included Co60, Cs137, and Eu152

Matrix Materials included shredded paper and mixed metals

Results of Six Participants

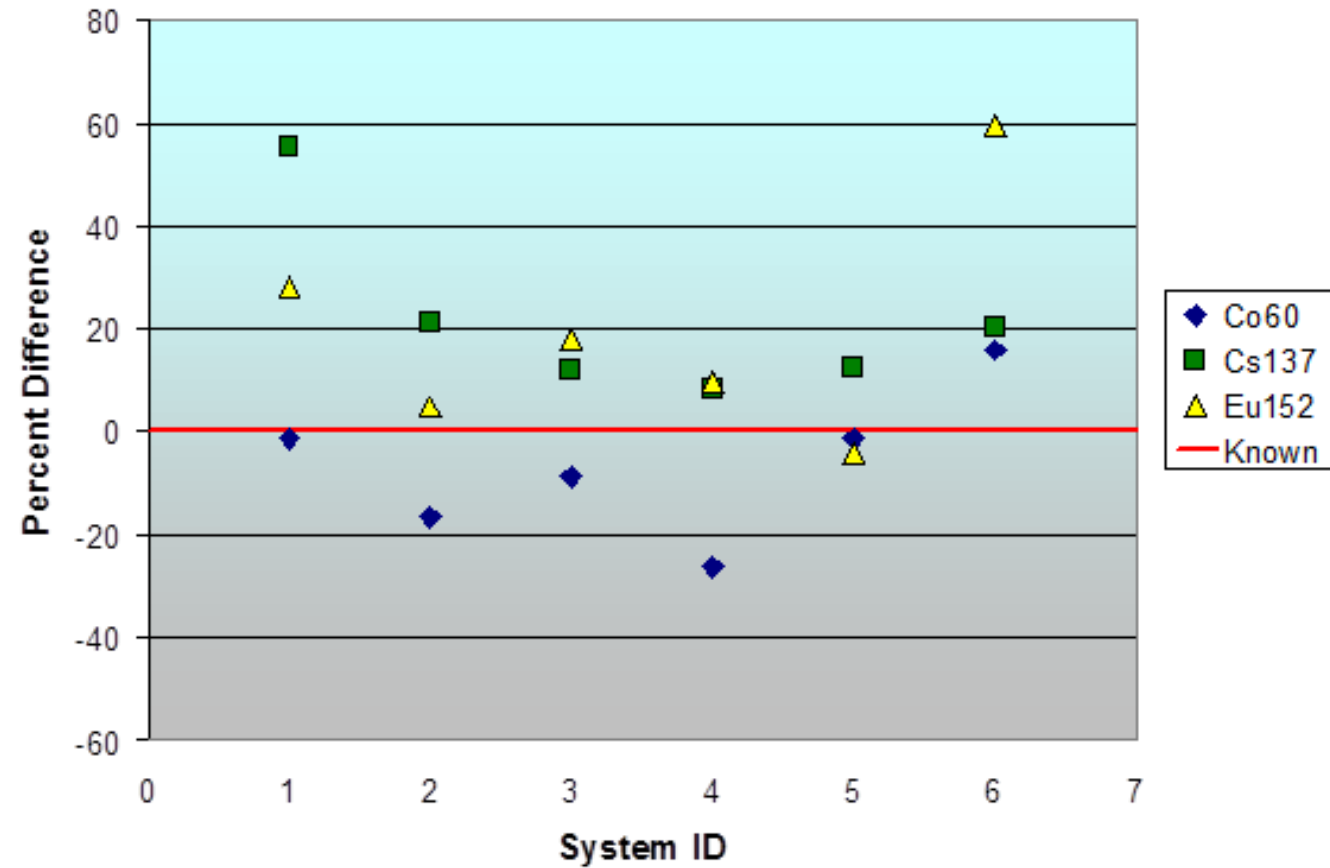


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Results of Six Participants

LANL SNAP Systems Circled in Red

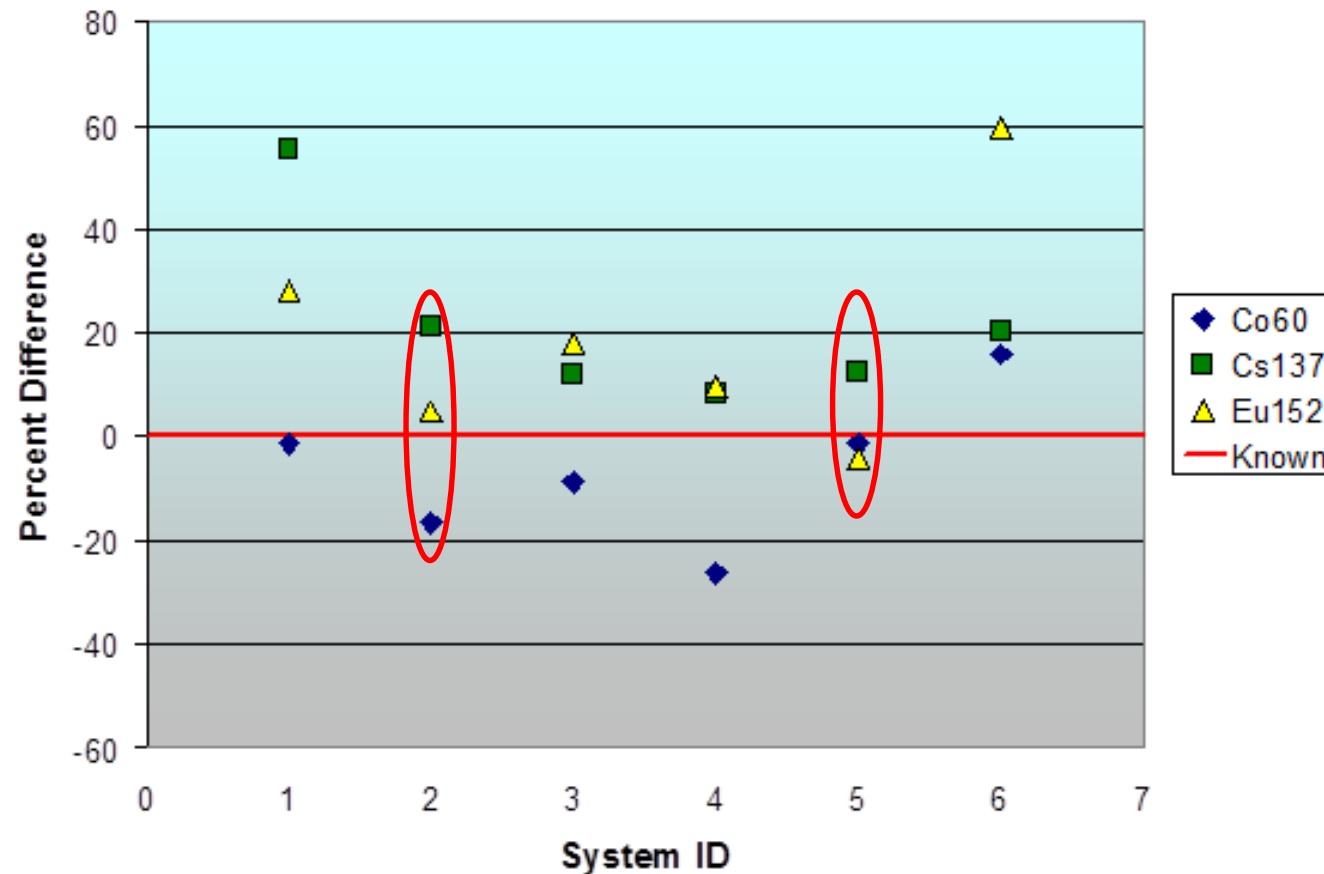


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More Verification Results



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| Pu Disc | Detector | Mass of Pu239 (g) | SNAP Result (g) | % Difference |
|---------|----------|-------------------|-----------------|--------------|
| Pu Disc | Tweety | 108 | 110.4 | 2.22% |

| U-233 Metals | Detector | Mass of U233 (g) | SNAP Result (g) | % Difference |
|---------------|------------|------------------|-----------------|--------------|
| Metal Piece 1 | Roadrunner | 107 | 100.0 | -6.54% |
| Metal Piece 2 | Roadrunner | 72 | 74.3 | 3.19% |

| Pu-238 Rods | Detector | Certified Mass of Pu238 (g) | SNAP Result (g) | % Difference |
|-------------|------------|-----------------------------|-----------------|--------------|
| STDSGPUL | Tweety | 0.0952 | 0.1012 | 6.32% |
| | Mickey | 0.0952 | 0.098 | 2.96% |
| | Sylvester | 0.0952 | 0.0912 | -4.20% |
| | Roadrunner | 0.0952 | 0.0932 | -2.10% |
| STDSGPUH | Bullwinkle | 0.5564 | 0.5878 | 5.64% |

| HEU Fuel Rods | Gross Weight of Rods (kg) | Certified Mass of U235 (g) | SNAP Result (g) | % Difference |
|---------------|---------------------------|----------------------------|-----------------|--------------|
| Lot 092 | 19.13 | 354.01 | 367 | 3.67% |
| Lot 097 | 21.08 | 106.13 | 109 | 2.70% |
| Lot 098 | 20.39 | 81.98 | 78 | -4.80% |
| Lot 099 | 6.12 | 129.74 | 129 | -0.59% |

Uranium Drum Verification Results



| HEU Standards in 55 Gal Drums | Detector | Certified Mass of U235 (g) | SNAP Result (g) | % Difference |
|----------------------------------|------------|-------------------------------|--------------------|--------------|
| STDSGUD1 | Tweety | 31.20 | 28.06 | -10.06% |
| | Mickey | 31.20 | 30.98 | -0.70% |
| | Bullwinkle | 31.20 | 30.50 | -2.24% |
| | Sylvester | 31.20 | 32.13 | 2.98% |
| | Roadrunner | 31.20 | 27.98 | -10.32% |
| STDSGUD2 | Tweety | 100.99 | 94.26 | -6.66% |
| | Mickey | 100.99 | 101.22 | 0.23% |
| | Bullwinkle | 100.99 | 101.58 | 0.59% |
| | Sylvester | 100.99 | 96.60 | -4.35% |
| | Roadrunner | 100.99 | 107.40 | 6.35% |

There were many others – mostly in waste drums

Summary

- All necessary corrections are carefully performed to allow for very good assay results of materials that are otherwise “not amenable to measurement” by traditional assay systems
- Several HPGe systems are certified to perform safeguards measurements at LANL
- MDA’s can be determined and a Special Modeling capability extends the potential use to many unique challenges